Factual Results of an Eight Year Application of the SOL Safety Event Analysis Methodology in a Hungarian Nuclear Power Plant

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Abstract: The objective of this paper is to summarize the factual results of eight year application of the SOL safety event analysis methodology for the period of 2007-2015 in a nuclear power plant in Hungary. After putting the SOL analyses into a wider context, 531 particular contributing factors were identified and classified into the 20 broad standard SOL contributing factor categories. It turned out that a 28 item "toplist" of the particular contributing factors altogether contains 236 out of the total of 531 – corresponding to about 44% – and their highest frequency socio-technical system component category was the "Organization" (118.50%), closely followed by the "Individual" (98.41%). Based on the identified contributing factors and their relative weights, the corrective measures taken could prevent these – or similar other – events from recurring.

Keywords: SOL; safety event analysis methodology; nuclear power plant

1 Introduction

1.1 Background

This paper is the first of two related papers providing the most fundamental parts of the experiences gained during the latest eight year use of the SOL (*Safety through Organizational Learning*) safety event analysis methodology in the MVM Paks Nuclear Power Plant Ltd. (hereafter Paks NPP) in Hungary. The Paks NPP is still the only nuclear power plant in Hungary, and it has four units in operation with VVER-440 reactors.

The fundamentals of the SOL methodology have already been published elsewhere in many journal articles and books, e.g. refer to [31], [14], [30], and

[12]. Apart from scientific publications listed above, some IAEA (International Atomic Energy Agency) and EC (European Commission) technical documents also review the SOL, refer e.g. to [17] and [11].

In short, the SOL is a sophisticated event analysis methodology for learning from events that already have happened. This is clearly an “analysis methodology” to facilitate organizational learning in a well-structured way, and not an “investigation methodology” for finding some persons to blame. This is a very effective in-depth methodology, especially capable of identifying organizational and leadership related problems. It has also to be mentioned, however, that applying the SOL is also relatively costly. It requires a thoroughgoing preparation (collecting all the relevant documents and facts concerning the given event), involving independent external experts (as moderators of SOL sessions), and taking out from duty the most involved 10–14 NPP employees, independently from their positions, for two and a half consecutive working days and providing them the necessary working conditions in a hotel as well.

The father of SOL was late prof. Bernhard Wilpert of the TU Berlin, with whom the first two authors of this paper had the possibility to cooperate in adapting the SOL to the conditions of the Paks NPP in the years 2000-2005. In 2006 we already presented the very first application experiences [23], and later published some of the experiences gained since then [1]. Nevertheless, the present paper is the first comprehensive and detailed summary of our results in English on applying the SOL in the Paks NPP.

After carrying out several pilot SOL analyses, and having convinced the top management of the Paks NPP, the safety director decided in 2006 on introducing the SOL methodology. The original idea was to compare the results gained by the SOL with the results of the usual routine event analysis methodology – called PRCAP (*Paks Root Cause Analysis Procedure*) – of the Paks NPP. The main features of the PRCAP can be found in [17] and in [11].

The SOL methodology finally was introduced into the organization of the Event Analysis Group of the Safety Directorate in 2007 on a regular basis, 3-4 analyses per year, as part of the efforts increasing safety. Already the first experiences had shown that the SOL is not simply an alternative to the PRCAP, but it is rather a powerful complementary approach especially capable of identifying organizational “contributing factors” and thus supporting individual and organizational learning, increasing safety attitude and awareness.

Always only such events have been selected for SOL analysis that previously had already been analyzed and officially closed by the PRCAP. Therefore the SOL is a kind of “posterior” methodology, to be used quite independently from the PRCAP. This way the goal of applying the SOL has never been finding someone to blame, but only learning from the experiences. The moderators of the SOL sessions have always been invited independent external experts – actually the three authors of this paper – having both NPP related technological and psychological qualification and experience. Selecting events for SOL analyses is done by the Safety Directorate, usually consulting with independent SOL experts.

As the leader of the Event Analysis Group of the Safety Directorate at the Paks NPP, Gergely, – from an internal NPP perspective focusing on the specific local circumstances – [15] compiled a summary of guidelines for applying the SOL at the Paks NPP. The most important guidelines that have been proven significant concerning the selection of participants:

- The directly involved persons should participate (to ensure direct experiences and memories be taken into account)
- The involved organizational units should be represented proportionally (to ensure the appropriate content of the SOL working group)
- Manager (if possible top manager) should always be participating (to ensure the presence of real decision makers)
- All the participants should be professionally competent concerning the given event (to ensure the widest possible sources of relevant knowledge and experiences be at service)
- The total number of participants should not exceed 15 (to ensure the optimal number of participants for the best possible group dynamics)

Further requirements for preparing the invited participants prior to SOL analyses:

- Take part in a preparatory SOL meeting organized by the Safety Directorate
- Study the PRCAP analysis protocol of the given event
- Collect all relevant written materials (documents, memos, warrants, etc.)
- In order to identify minor details that could later turn out to be important, diccuss the event with colleagues of the organizational unit
- Study several earlier SOL protocols available on the NPP intranet portal

In the Paks NPP the instruction and training of employees is of high priority, the instruction and training system is diversified and multilevel. Based on the SAT (*Systematic Approach to Training*) concept of the IAEA the activity spectrum covers areas from general basic courses for new employees via professional basic education and refresher training, full scope simulator training for the control room crew, to practical training for the maintenance personnel.

The Paks NPP has a large Training Center under the Human Resource Directorate employing about 60 staff. In addition to the professional instructors, there is a network of so-called “qualified instructors”, who are outstanding specialists with high reputation in their own fields. These “qualified instructors” have acquired the pedagogical, psychological and communicational skills necessary for effective instruction and training in the frame of special adult education.

In the dissemination of the SOL results the Training Center is the key actor. Since the introduction of SOL, the Training Center has gradually become active in transmitting the results of SOL analyses toward the production, technology and maintenance areas. Utilizing the results via instruction and training is now a high priority expectation from the top management toward the Training Center. All the protocols of completed SOL analyses are continuously available for the employees on the intranet portal.

The initial disapproval because of the skepticism and relatively high costs has already disappeared. Since 2015 all the results of the SOL analyses have also to be discussed at the meetings of the Operational Review Committee. By this time the SOL analyses have been built into the internal regulation system of the Paks NPP.

Applying the SOL this way has been a real success story: since its introduction in 2007 till now altogether 32 SOL analyses have already been completed, revealing many organizational and leadership related problems that – as confirmed by the experiences – could not have been identified by the usual PRCAP analysis methods. The PRACP method, even if applied more thoroughly, could not have the capability of yielding more insights into organizational and leadership related problems, because of the inner limits of this method. The PRACP is a very useful, but much simpler, more routine and cheaper method in comparison with SOL which was designed mainly to identify organizational and leadership related problems.

In 2013 the WANO (*World Association of Nuclear Operators*) declared the SOL application practice in the Paks NPP as a “good practice” and proposed adapting this methodology for the nuclear communities of the world.

Based on this, among many others, the IAEA OSART (*Operational Safety Review Team*) in its 2014 report on the Kozloduy Nuclear Power Plant, Bulgaria, contains proposals for introducing the SOL [18].

1.2 Research Questions

The goal of this paper is to present the main factual results of the 27 SOL analyses — and the related four SOL meta-analyses — completed in the period of March 2007 – May 2015, totaling up to about 8 years.

Before focusing on this SOL target period of 2007-2015, we first place the main recorded safety characteristics of this period into a wider context in terms of time and also in terms of deviation types, professional areas of deviations, organizational areas responsible for treating deviations, and corrective measure types taken. It was hoped that this way we could get a more realistic picture about the “sampling basis” for selecting events for deeper SOL analyses.

Commencing with the introduction of SOL in 2007, in every second year SOL meta-analyses have been carried out aiming at identification of the most relevant particular contributing factors for these respective sub-periods. The 20 broad factor categories of possible contributing factors are precisely defined in the SOL terminology and are the following:

(1) Technological components, (2) Information presentation, (3) Communication, (4) Working conditions, (5) Personal performance, (6) Rule violation, (7) Operation scheduling, (8) Responsibility, (9) Control and supervision, (10) Group influence, (11) Rules, procedures and documents, (12) Personal qualification, (13) Training, (14) Organization and management, (15) Feedback of experience, (16) Safety principles, (17) Quality management, (18) Maintenance, (19) Regulatory and consulting bodies, (20) Environmental influence.

The main research questions, concerning the target period for applying the SOL, were to determine the frequency distributions of the identified contributing factors and how to interpret them.

2 Methods

2.1 Approach

The theoretical frame of the SOL methodology was developed basically from the widely known so called “Swiss-Cheese Model” [26], and from the “socio-technical system model” specifically designed for the nuclear industry [4]. These two event causation models were combined with the organizational learning approach. This frame serves at the same time as the theoretical basis of this research too, presented here in this paper.

The “Swiss Cheese” metaphor is an expressive accident causation model using the concept of layered security (defense in depth). It likens the different sub-systems of the “socio-technical system” to multiple slices of Swiss cheese, stacked side by side, in which the hazards (potentially harmful effects) could – or could not – pass through the holes of these slices as defense layers. The main components of the “socio-technical system” are the “Individual”, the “Group”, the “Organization”, the “Technology” and the “Environment” domains. The relevant defense layers could be in the areas of any sub-sub-systems of these main components. More details on Reason’s views about these topics can be found in [27] [28] [29].

Learning from (especially negative) experiences (like accidents, incidents, errors, etc.) is an essential determinant of successful operation in high-risk socio-technical systems. This learning is a human activity that can take place in the domain of “Individual”, or/and “Group”, or/and “Organization” socio-technical system components. As an example, we, in cooperation with Paks NPP, also developed and operated a practical computer-supported method for fostering individual and group (team) level learning in situations immediately after simulator training sessions: [2] [21]. The SOL, however, targets directly the learning at organization level, which is far the most important domain.

By the SOL terminology, events (occurrences of unexpected, undesirable system states) can be described as causal and temporal chains of elementary sub-events called "event building blocks". Events occur through interaction of different contributing factors working on the domains of any socio-technical system components.

A SOL event analysis is the later reconstruction of the occurrence of an event as well as of its causes in the sense of a root-cause analysis. For root-cause analysis in a NPP, refer to [19].

The SOL was especially designed to identify organizational (including management, leadership, procedures, documentation, etc. related) problems, and the practice has shown that the SOL is really very capable of doing this.

Our view is rather radical concerning the organizational factors: we believe that, in a wider sense, the final root-causes are very often – almost always – located within the domain of the "Organization" socio-technical system component. If this causal relationship cannot be proven, the analysis probably has not delved deep enough. After such a statement, one could question the role of the "Individual", "Group", "Technology" and the "Environment" components. Actually, these can be considered as some kind of intermediate or transition components that would sooner or later lead to the Organization component. The key in the SOL methodology to labeling a problem domain as "Individual", "Group", "Organization", "Technology" or "Environment" is the answer to the question: "*Given the present state of the art, can the prevention of this very problem/failure/flow be expected from this very organization?*". The main aspect is "sooner or later": what cannot be expected from an organization today, can well be expected tomorrow.

There are many examples in the literature for cases that first clearly seemed to be associated with individual, group or technology level error, but a deeper analysis later revealed that in reality it is – at least partly – an organization level error.

A good example is the case of the disaster of freight ferry Herald of Free Enterprise in 1987, when the assistant bosun – although it was his duty – did not close the bow doors, since at this time he was asleep in his cabin instead. This fact, however, gets a quite different judgment if we get to know that before falling asleep the assistant bosun was already on duty for about 24-hours, and therefore suffered from sleep deprivation [16, page 61].

This way the label "individual error" suddenly was transformed into mainly "organization error": the company required him to be for 24 hours on duty. Literally the following can be found in the corresponding judicial document [10, page 14]: "At first sight the faults which led to this disaster were the aforesaid errors of omission on the part of the Master, the Chief Officer and the assistant bosun, and also the failure by Captain Kirby to issue and enforce clear orders. But a full investigation into the circumstances of the disaster leads inexorably to the conclusion that the underlying or cardinal faults lay higher up in the Company."

In this same disaster, the balancing group in the ship's bottom inappropriately balanced the weight, and the embarking group carelessly counted the passengers that led to a serious 13% overload. At first sight these seemed to be group level errors, but later it turned out that these are predominantly also organization level errors, since the management tacitly accepted and tolerated this risky behavior already for a long time.

Similarly, the facts that the ferry had a top-heavy design, her body was not subdivided into watertight compartments, and there was an uncorrected leaning to the right, first seemed to be associated with technological (design or equipment) level errors. The deeper analysis, however, revealed again that these are predominantly also organization level errors, since the management knew these technological problems but tolerated them without taking any corrective measures. Further details are available e.g. in [24, page 129] and in [25].

Another example from our own practice for causing or preventing human errors at "Individual" level by means of "Organization" level regulation is presented in [22]. We found that NPP control room operators during normal – and therefore relatively uneventful – shifts experience a kind of rather strong "arousal compensation tendency" that influences their subjective well-being. We concluded that it is safer to allow for operators certain kinds of not directly task-related voluntary activities (like not task-related conversation, listening to the radio, etc., of course within reasonable limits) than expect them strictly doing nothing and being under stimulated during long eventless periods of operation.

This view, concerning human error (should it be at "Individual", "Group", or "Organization" level), is in perfect agreement with Dekker's "New View of Human Error", refer to [6]. In this book (page 159) Dekker states that "A human error problem is an organizational problem. Not because it creates problems for the organization. It is organizational, because a human error problem is created, in large part, by the organization in which people work."

Right in the preface of this book (Table 0.1, page xi) Dekker summarizes the characteristics of the "Old View" and the "New View" of Human Error in the following way (direct quotations):

The Old View of Human Error on what goes wrong	**The New View of Human Error on what goes wrong**
Human error is a cause of trouble.	Human error is a symptom of trouble deeper inside a system.
To explain failure, you must seek failures (errors, violation, incompetence, mistakes).	To explain failure, do not try to find where people went wrong.
You must find people's inaccurate assessments, wrong decisions, and bad judgments.	Instead, find how people's assessments and actions made sense at the time, given the circumstances that surrounded them.

The Old View of Human Error on how to make it right	The New View of Human Error on how to make it right
Complex systems are basically safe.	Complex systems are not basically safe.
Unreliable, erratic humans undermine defenses, rules and regulations.	Complex systems are trade-offs between multiple irreconcilable goals (e.g. safety and efficiency).
To make systems safer, restrict the human contribution by tighter procedures, automation, and supervision.	People have to create safety through practice at all levels of an organization.

More details on Dekker's views about these topics can be found in [5] [7] [8] [9].

It has also to be stressed that behind the "Technology" and the "Environment" related contributing factors a thorough analysis usually (but, of course, not always) also reveals the "Organization" level root causes.

If e.g. a faulty piece of machinery represents a "Technology" related contributing factor of a particular event, the causal chain can be followed backwards and the questions rightfully arise:

- Why has the "Organization" purchased this particular piece of machinery?
- If it went wrong only after a longer use, why the "Organization" has not provided appropriate and effective preventive maintenance?

Similarly, if e.g. a sudden unexpected weakening of the market position of the company represents an "Environment" related contributing factor of an event, the following questions are appropriate:

- Why was this concrete loss of position a surprise for the "Organization"?
- Why the "Organization" has not prepared itself for such economic turbulences?

2.2 Applied Methods

We share Dekker's opinion [6] that simply counting human errors cannot be a valid and meaningful approach in NPP safety research, because it is hard to agree what an "error" really is. Instead of identifying and counting human errors we are focusing on identifying and counting deviations and contributing factors.

Therefore our basic methods were

- Studying of the event analysis data gained by the PRCAP methodology during the period of 1999-2014 in broad terms of deviation types, professional areas of deviations, organizational areas responsible for treating deviations, and measure types taken as functions of time.

- Detailed analysis of the results gained by the SOL methodology in the period of 2007-2015 via focussing on identified contributing factors.

These analyses are based on the PRCAP and SOL data bases and basically comprise comparing frequencies in different categories derived from deviations and contributing factors. Because of the nature of these data, either merely descriptive statistics were considered, or simple nonparametric statistical tests were applied.

3 Results

3.1 The Wider Context

Before focusing on the target period of March 2007 – September 2015, this period was taken into a wider context in terms of time, deviation types, professional areas of deviations, organizational areas responsible for treating deviations, and measure types taken. These pieces of information can be seen in Figures 1, 2, 3 and 4.

This way we could get a more realistic picture about the “sampling basis” for selecting events for SOL analysis. In the period of January 1999 – November 2014 the Safety Directorate of the Paks NPP altogether investigated 624 events, including a total of 2236 deviations.

A deviation is defined as any shift from standard practice or parameter value. A violation is a deliberate deviation from standard practice, carried out to maintain safe operation.

The number of deviations per event is quite steadily 3.58 throughout this period (min=1, max=26, SD=2.97).

Root causes are the fundamental causes of a deviation in a causal chain that if corrected, will prevent recurrence of this deviation.

Direct causes are the latent weaknesses that allow or cause the observed cause of an initiating event to happen, including the reasons for the latent weakness.

Contributing cause (factor): a condition that may have affected the occurrence of a deviation.

It can be observed in all the Figures 1, 2, 3 and 4 that from 2005 there is a radical decrease in the number of events, and consequently also in the number of deviations. Its reason is very probably – in accordance with the opinions of the leading safety experts of the Safety Directorate of the Paks NPP – that following the INES (*International Nuclear Event Scale*) level 3 event that occurred in 2003 certain severe safety measures have been taken step by step and simultaneously the general awareness for preventing human errors has also increased. It has also to be taken into account that the deviation reporting criteria significantly changed in August 2013.

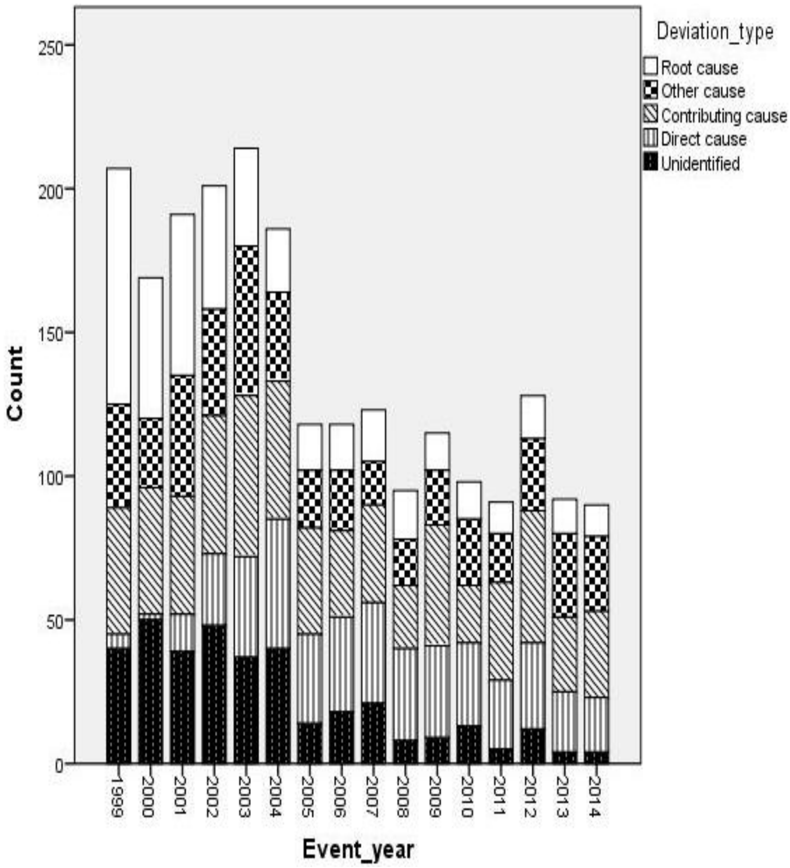

Figure 1

Frequencies of different deviation types as a function of time in years

It is also clear from the Fig. 1 that the number of identified root causes continuously decreases along the whole time period. Simultaneously, the number of identified direct causes steeply increases till 2004, and after that slightly decreases. Important background information is that each event has at least one identified direct cause. Complex events may even have two direct causes, but more than two usually cannot be found.

A more detailed analysis has shown that this changing pattern is true not just for the absolute numbers of root causes (and of direct causes), but also for the ratio of root cause numbers to total cause numbers (and for the ratio of direct cause numbers to total cause numbers).

The total number of identified root causes for this period was 428, which means that it was possible to find root causes only for about 68% of the events.

It was found that the ratio of total number of causes to the number of root causes starts at about 2 in 1999, and after a slight continuous increase, in 2004 jumps to about 7, and its final value is about 9 in 2014.

Our interpretation is that after the INES level 3 event in 2003, as a result of the new and rather severe safety measures taken, (1) a smaller number of such events occurred that had to be investigated by the PRCAP methodology, and (2) the analysis have become more thorough. These are reflected in the fact, that with one root cause an increasing number of other causes are associated.

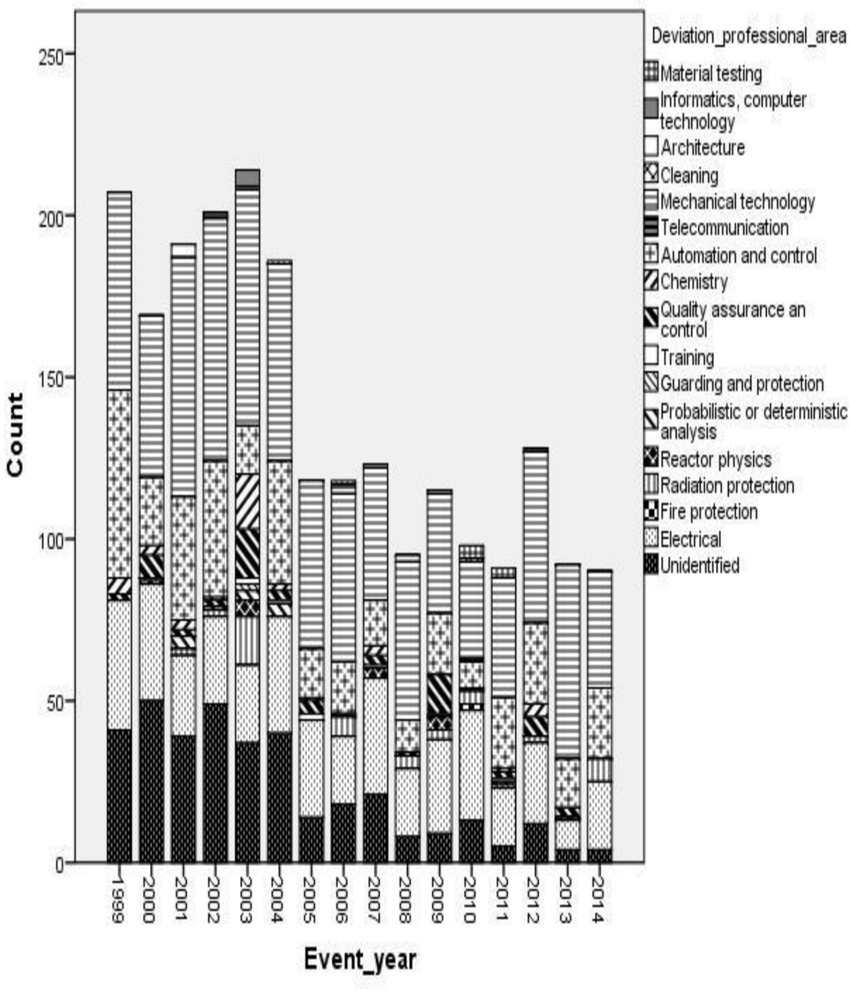

Figure 2

Frequencies of different professional areas of deviations as a function of time in years

It can be seen that the most involved professional area is the mechanical technology, which is followed by the electrical technology and by the automation and control.

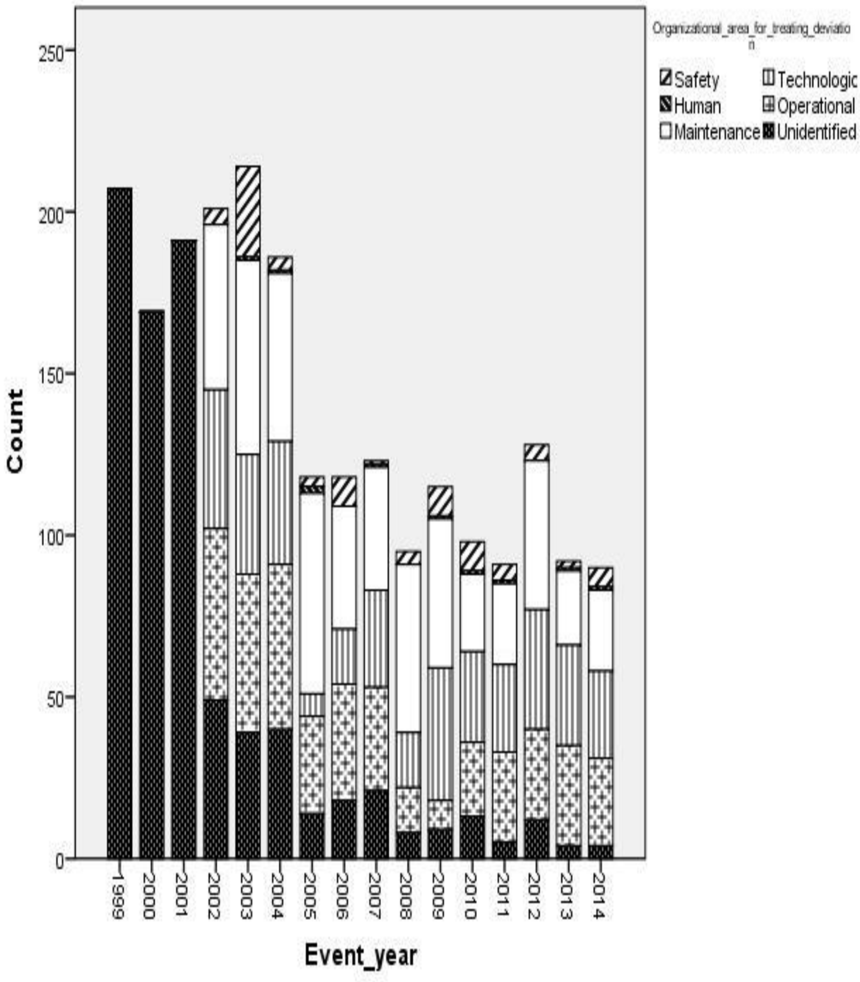

Figure 3

Frequencies of different organizational areas responsible for treating deviations as a function of time in years

It can be seen that the most frequently involved organizational area is the maintenance, which is followed by the operation and by technology.

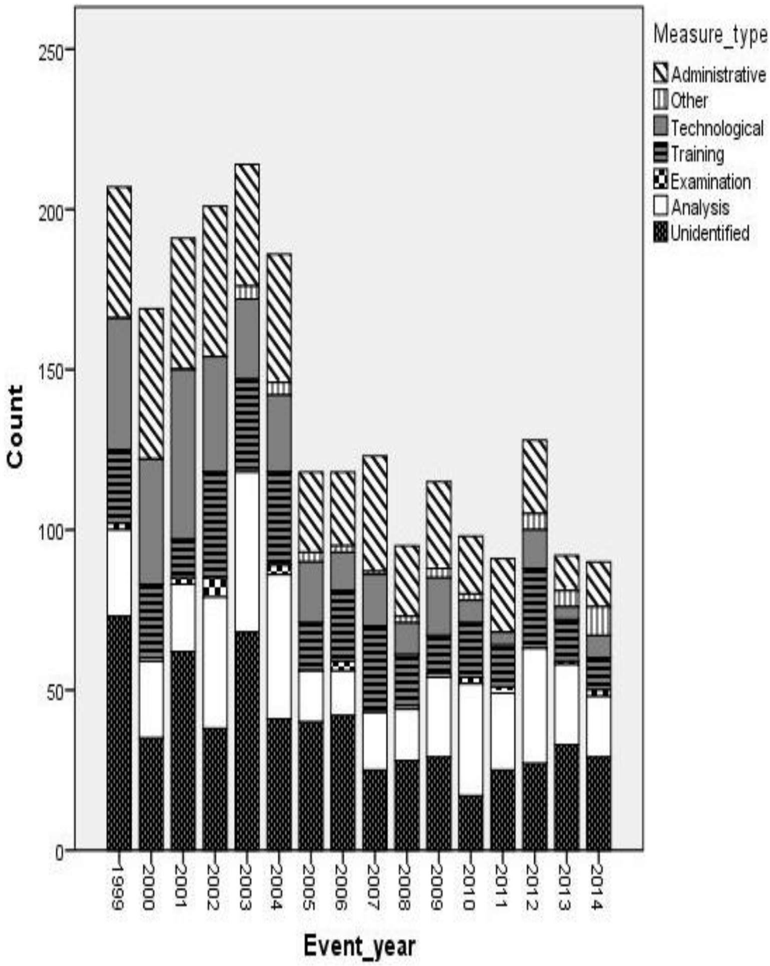

Figure 4

Frequencies of measure types taken by the organization as responses for the deviations as a function of time in years

In this figure we can see that the most frequently involved measure type taken is administrative, which is followed by technological, analysis and training measures.

3.2 Results Gained by the SOL Methodology in the Period of 2007-2015

From the above it follows that within our whole target period of interest (2007-2015) the selection of events for SOL analysis during the first three two-year sub-periods (2007-08, 2009-11, 2011-13) had been done from among events investigated by the same criterion system. During the last sub-period (2013-15), however, different criteria were used for the analysis – which although directly surely have not influenced the process of selecting events for SOL analysis – for only the order's sake the results of this last sub-period were analyzed separately. As the results later showed, and as expected, there were really no differences.

From the above it can also be seen that in the period of January 1999 – November 2014 (for which the Safety Directorate of the Paks NPP had final processed event analysis data at the time of closing the manuscript of this paper) altogether 624 events were investigated. From these events 218 occurred and were investigated in the period of 2007-2014. Of these 218 events – of which only a very small fraction was officially labeled as "safety relevant" – 25 were selected for the deeper SOL analysis, corresponding to about 11%. This percentage has always to be kept in mind while trying to generalize SOL results.

The frequency distribution of the 531 contributing factors identified in the period of 2007-2015 along the four sub-periods of the corresponding SOL meta-analyses can be found in Table 1, while the distribution of these contributing factors along the 20 broad factor categories can be seen in Table 2.

Table 1
The frequency distribution of the 531 contributing factors identified in the period of 2007 – 2015 along the four sub-periods of the SOL meta-analyses

Sub-period of SOL meta-analyses	**2007-2008**	**2009-2011**	**2011-2013**	**2013-2015**	**Total**
Number of SOL analyses completed	8	8	6	5	27
Number of identified contributing factors	182	135	129	85	531

Taking into account that the deviation reporting criteria changed in August 2013, the statistical analysis first compared only the first three sub-periods by the chi-square test. This analysis, however, has not revealed any time effects: there were no significant differences between the numbers of identified contributing factors of the first three sub-periods. It has also been proven, that – despite the change of reporting criteria in August 2013 – there were no statistically significant differences between the frequencies of identified contributing factors of the first three sub-periods (taken together) and of the fourth sub-period.

This time-independence was also true not just for the total numbers of identified contributing factors (as presented in Table 1), but also separately for each of the 20 broad factor categories (as presented in Table 2). This means, that even if in reality there do exist some increasing numbers of time-dependent deviations as was originally presupposed by us due to the ageing of the NPP, it was not possible to prove it during this relatively short eight year period by our relatively incomplete and insensitive methods. We have also to recall, that the SOL sampling rate was only about 11% of the all events of the target period.

Notwithstanding, during the SOL sessions we sporadically have heard such pieces of information that support the hypothesis of increasing number of age-related deviations. Examples: to certain older soviet made equipment certain documents or component parts, accessories and fittings are not always available in time. In some cases even the original manufacturers of these components are not available either.

Table 2

The frequency distribution of the 531 contributing factors identified by the SOL methodology in the period of 2007 – 2015 along the 20 broad contributing factor categories and the 5 socio-technical system components

ID code	Broad contributing factor category	Total frequency of 2007-2015	%	Socio-technical system component
1	Technological components	48	9.04	Technology
2	Information presentation	17	3.20	Technology
3	Communication	35	6.59	Individual - Group
4	Working conditions	37	6.97	Organization
5	Personal performance	95	17.89	Individual
6	Rule violation	49	9.23	Individual
7	Operation scheduling	16	3.01	Organization
8	Responsibility	17	3.20	Organization
9	Control and supervision	16	3.01	Organization
10	Group influence	3	0.56	Group
11	Rules, procedures and documents	59	11.11	Organization
12	Personal qualification	3	0.56	Organization
13	Training	6	1.13	Organization
14	Organization and management	91	17.14	Organization
15	Feedback of experience	13	2.45	Organization
16	Safety principles	3	0.56	Technology
17	Quality management	6	1.13	Organization
18	Maintenance	5	0.94	Organization
19	Regulatory and consulting bodies	7	1.32	Environment
20	Environmental influence	5	0.94	Environment
Sum total		531	100.00	All

Table 3
The "top list" of particular contributing factors identified by the SOL methodology in the period of 2007-2015

	Concrete particular contributing factors of the highest total frequencies identified in the period of 2007-2015	**Socio-technical system component**	**Total frequency of 2007-2015 (at least 5)**
1	Omitted activity	Individual	25
2	Lack of following procedures	Individual	18
3	Incomplete documentation	Organization	13
4	Documentation not necessarily detailed	Organization	10
5	Time pressure or performance urge	Organization	10
6	Design error of technical component	Technology	10
7a	Incomplete or unsatisfactory communication*	Group	9 (5)
7b	Incomplete or unsatisfactory communication*	Individual	9 (4)
8	Unsatisfactory attention for details	Individual	9
9	Important information delayed to forward or lost	Individual	8
10	Not recognizing the real importance of task	Individual	8
11	Tolerating general practice that - at least partly - violate rules	Organization	8
12	Unsatisfactory control and supervision	Organization	8
13	Missing resources (human, financial, time, etc.) for achieving goals	Organization	8
14	No organizational level regulation concerning identified problems	Organization	7
15	Disturbing working conditions, significant workload	Organization	7
16	Complacency based on past experiences	Organization	7
17	Error in performing a task	Individual	7
18	Work performance that – at least partly – violates rules	Individual	7
19	Not observing procedures	Individual	7
20	Unsatisfactory change management	Organization	7
21	Missing documentation	Organization	6
22	Missing warning signal before safety intervention	Organization	6
23	Management does not treat a problem according to its importance	Organization	6
24	Making an error or misjudgment	Individual	5
25	Unsatisfactory briefing before performing tasks	Group	5
26	Unsatisfactory human resource allocation	Organization	5

27	Preferring production or economic aspects against safety	Organization	5
28	Not introducing necessary measures against known problems	Organization	5
Sum total		All	236

Comments:
(1) * The frequency of 9 of the "Incomplete or unsatisfactory communication" contributing factor was divided between the "Group" and "Individual" socio-technical system component categories.

(2) Since there were no statistically significant differences between the frequencies of the identified contributing factors during the four sub-periods, here the whole period of 2007-2015 is treated together.

The following bar chart presents the distribution of these 236 contributing factors along the socio-technical system components.

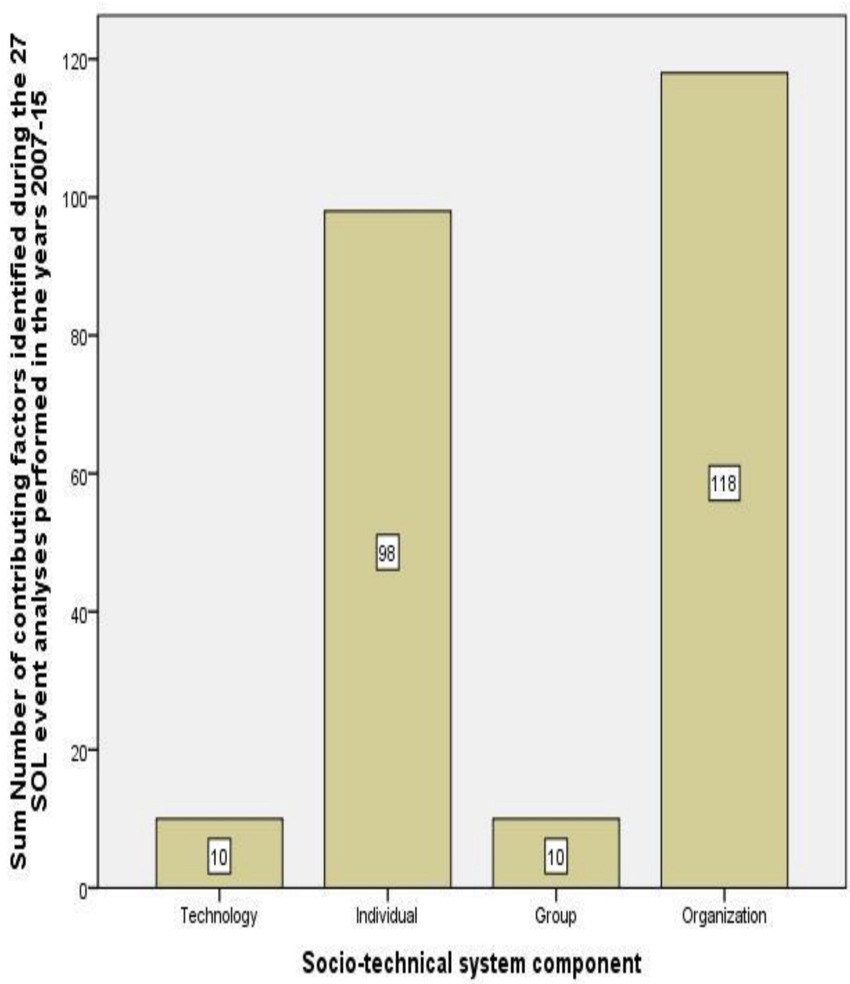

Figure 5
Bar chart of the frequencies of the identified 236 particular contributing factors of the highest total frequencies belonging to different socio-technical system components for the SOL analyses period of 2007-2015

The frequencies in the different socio-technical system component categories in Fig. 5 were calculated from the "top list" frequencies of particular contributing factors shown in Table 3.

Important to note, that from the data in Table 2 a bar chart very similar to Fig. 5 could have been constructed, but since the "top list" in Table 3 (and the related Fig. 5) contains much fewer items, it is also much easier to interpret.

4 Discussion

The "top list" shown in Table 3 is considered to be the main and practically most usable summary results of the SOL analyses. It presents those concrete particular contributing factors the total frequencies of which are at least 5. These 28 particular contributing factors altogether contain 236 out of the total of 531, corresponding to about 44%. These contributing factors indicate those identified problems for the elimination (or at least mitigation) of which corrective measures had to be taken. The big majority of these measures really have been taken. Concerning the perceived utilization efficiency of these measures please refer to the continuation of this paper titled "*Impact assessment of eight year application of the SOL safety event analysis methodology in a nuclear power plant*" published in the same issue of this journal.

Not surprisingly, the highest frequency socio-technical system component category was the "Organization", closely followed by the "Individual". Although half of all the identified contributing factors fell into the "Organization" category, on principal basis we have good reasons to think that even deeper SOL analyses could have categorized an even greater part of "Individual" factors into "Organization".

On the other side, in the practice there is no need for such "even deeper SOL analyses", because the applied SOL analysis in its present form is deep enough for all practical purposes. Our radical view that the final root-causes are almost always located within the domain of the "Organization", in itself, is not concrete enough and therefore is useless in the practice. The real practical strength of this view during SOL analysis lays in encouraging the attitude of:

- Fact-finding (not searching for scape-goats)
- Avoiding premature or insufficient generation of hypotheses
- Avoiding mono-causal thinking and truncated search strategies

If doing so, apart from that the overwhelming a majority of final root-causes, almost always, will be located within the "Organization" domain. The analyzed concrete events will be correctly reconstructed and deeply understood in more detail. This way, based on the identified contributing factors and their relative weights, the corrective measures taken, could prevent these or similar other events from recurring.

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